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FORM PTO-1390 (Modified) (REV 10-95) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		ATTORNEY'S DOCKET NUMBER **9847-0050-6X PCT** U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 09/554914
INTERNATIONAL APPLICATION NO. **PCT/SE98/02163**	INTERNATIONAL FILING DATE **27 NOVEMBER 1998**	PRIORITY DATE CLAIMED **27 NOVEMBER 1997**

TITLE OF INVENTION

A ROTATING ELECTRIC MACHINE WITH A MAGNETIC CORE

APPLICANT(S) FOR DO/EO/US

Jan HEMMINGSON

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
    A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☒ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report
Notice of Priority
Marked-up Specification
Response to Petition
List of Related Cases
Citation List - Alternate Form PTO-1449

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9847-0050-6X PCT
ENKEL 8337

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF:

JAN HEMMINGSSON : ATTN: APPLICATION DIVISION

SERIAL NO: NEW APPLICATION
(BASED ON PCT/SE98/02163)

FILED: HEREWITH

FOR: A ROTATING ELECTRIC MACHINE
WITH A MAGNETIC CORE

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, DC 20231

SIR:

Prior to examination on the merits, please amend the above-identified patent application as follows:

IN THE CLAIMS

Please cancel without prejudice or disclaimer Claims 1-17.

Please add new Claims 18-35 as follows:

--18. A rotating electric machine comprising:

a magnetic core with a center axis that defines

an axial direction of said magnetic core,

a radial direction of said magnetic core, and

a circumferential direction of said magnetic core,

said magnetic core having a plurality of slots, each of said plurality of slots having walls,

a slot width being a distance between said walls,

a slot longitudinal direction with an axial directional component,

a slot transverse direction with a radial directional component,

said slot longitudinal direction and said slot transverse direction being defined by a center plane between said walls; and

an electric winding with a plurality of winding parts that extend in said slot longitudinal direction and arranged in each of said slots,

at least some of said plurality of winding parts being located radially displaced in relation to one another,

said electric winding having

an electric conductor configured to hold a high voltage, at least one full winding turn of said electric conductor being configured to confine an electric field in said electric conductor, wherein

at least one pair of adjacently located winding parts in a same slot being displaced in the circumferential direction relative to each other.

19. A rotating electric machine according to claim 18, wherein:

said at least one pair of adjacently located winding parts being a radially innermost part of an outer winding part and located radially inside an outermost part of an inner winding part.

20. A rotating electric machine according to claim 18, wherein:

at least two pairs of said at least one pair of adjacently located winding parts in said same slot being displaced in the circumferential direction in relation to each other and having a displacement being greater the further outwards, in said radial direction, the winding parts are located.

21. A rotating electric machine according to claim 18, wherein:

at least one of said plurality of slots having a directional component in said circumferential direction of said magnetic core along at least part of said slot transverse direction.

22. A rotating electric machine according to claim 21, wherein:

at least one of said plurality of slots being at least partially curved in said transverse

direction.

23. A rotating electric machine according to claim 22, wherein:
each of said plurality of slots being curved along said transverse direction, and each of said plurality of slots having a same radius of curvature.

24. A rotating electric machine according to claim 18, wherein:
said plurality of slots being parallel in both said longitudinal direction and said transverse direction.

25. A rotating electric machine according to claim 18, wherein:
at least one of said plurality of slots having an increased width outwards along said transverse direction.

26. A rotating electric machine according to claim 18, wherein:
at least one of said plurality of slots having a constant width in said transverse direction.

27. A rotating electric machine according to claim 18, wherein:
at least one of said plurality of slots having in said transverse direction alternating larger width portions and alternating smaller width portions.

28. A rotating electric machine according to claim 27, wherein:
at least one of said alternating larger width portions having a varying width.

29. A rotating electric machine according to claim 27, wherein:
said alternating larger width portions having a mutually similar width.

30. A rotating electric machine according to claim 18, wherein:
said at least one full winding turn of said electric conductor being flexible.

31. A rotating electric machine according to claim 18, wherein:
said electric conductor having

an inner semiconducting layer surrounding said electric conductor,

an insulating layer surrounding said inner semiconducting layer, and

an outer semiconducting layer surrounding said insulating layer.

32. A rotating electric machine according to claim 31, wherein:

each of said inner semiconducting layer and said outer semiconducting layer constitutes an equipotential surface.

33. A rotating electric machine according to claim 32, wherein:

said inner semiconducting layer, said insulating layer, and said outer semiconductor layer adhere to one another along a full turn of the electric winding, and

said inner semiconducting layer and said outer semiconducting layer having a substantially same coefficient of thermal conductivity as said insulating layer.

34. A rotating electric machine according to claim 31, wherein:

said inner semiconducting layer, said insulating layer, and said outer semiconductor layer being dimensioned to hold a voltage in said electric conductor being greater than 72 kV.

35. A rotating electric machine comprising:

a magnetic core with a center axis that defines

an axial direction of said magnetic core,

a radial direction of said magnetic core, and

a circumferential direction of said magnetic core,

said magnetic core having a plurality of slots, each of said plurality of slots having

walls,

a slot width being a distance between said walls,

a slot longitudinal direction with an axial directional component,

a slot transverse direction with a radial directional component,

said slot longitudinal direction and said slot transverse direction being defined by a center plane between said walls; and

an electric winding with a plurality of winding parts that extend in said slot longitudinal direction and arranged in each of said slots,

at least some of said plurality of winding parts being located radially displaced in

relation to one another,

said electric winding having

an electric conductor having means for holding a high voltage, and

means for containing an electric field in said electric conductor.--

IN THE ABSTRACT OF THE DISCLOSURE

After the last page of the specification, please insert the following Abstract of the Disclosure.

--ABSTRACT OF THE DISCLOSURE

A rotating electric machine with a magnetic core. The core is provided with slots for a winding. According to the invention, the winding comprises an electric conductor for high voltage. During at least one full winding turn, the winding essentially encloses its electric fields. Further, according to the invention, the winding parts in a slot are displaced in the circumferential direction relative to each other.--

REMARKS

Favorable consideration of this application as presently amended and in light of the following discussion is respectfully requested. Claims 18-35 are pending, Claims 1-17 having been canceled without prejudice or disclaimer and Claims 18-35 having been added by way of the present amendment. New Claims 18-35 find support in original Claims 1-17, and thus add no new matter. An Abstract has been added, consistent with U.S. patent drafting procedure.

Because several amendments have been made to the specification, consistent with U.S. patent drafting practice, a substitute specification is filed herewith in addition to a marked-up copy of the original application. Please enter this substitute specification. To the extent any changes made by the substitute specification are deemed to be substantively inconsistent with the originally filed specification, these changes should be construed as typographical errors and the language included in the originally-filed PCT application should be construed as containing the controlling language.

The present document is one of a set of patent applications containing related technology as was discussed in "response to petition under 37 C.F.R. §1.182 seeking special treatment relating to an electronic search tool, and decision on petition under 37 C.F.R. §1.183 seeking waiver of requirements under 37 C.F.R. §1.98," filed in the holding application (U.S. Patent Application No. 09/147,325). Consistent with this decision, a copy of the decision is filed herewith. Also, an Information Disclosure Statement is filed herewith including a PTO Form 1449 with references that are included as part of the specially-created official digest in class 174. It is believed that submission of these materials and the reference to the holding application (Serial No. 09/147,325) is sufficient for the present Examiner to consider the references in the holding application, consistent with the decision.

In view of the present amendment and in light of the foregoing comments, an examination on the merits is believed to be in order and an early and favorable action is respectfully requested.

Respectfully submitted,

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Marked up, Specification

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TITLE OF THE INVENTION

A ROTATING ELECTRIC MACHINE WITH A MAGNETIC CORE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a rotating electric machine.~~ of the kind described in the preamble to claim 1.~~

The rotating electric machines which are referred to in this context ~~comprises~~ are synchronous machines, which are substantially used as generators for connection to distribution and transmission networks, commonly called power networks. The synchronous machines are also used as motors as well as for phase compensation and voltage control, and, in that case, as mechanically idling machines. This technical field also ~~comprises~~ includes normal asynchronous machines, double-fed machines, AC-machines, asynchronous converter cascades, external pole machines and synchronous flux machines. These machines are intended to be used at high voltages, by which are meant here electric voltages which primarily exceed 10 kV. One typical field of operation for such a rotating machine may be 36 - 800 kV, and preferably 72.5 - 800 kV.

Discussion of the Background

Rotating electric machines have conventionally been designed for voltages within the interval 6 - 30 kV, whereby 30 kV has normally been considered to be an upper limit. In the generator case, this normally implies that a generator must be connected to the power network over a transformer which steps up the voltage to the level of the network, which lies within the range of about 130 - 400 kV.

Over the years, various attempts have been made to develop special synchronous machines, preferably generators, for high voltages. Examples of this are described, inter alia, in "Electrical World", October 15, 1932, pages 524-525, the article "Water-and-Oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pages 6-8, and patent

publications US 4,424,244 and SU 955 369. However, none of these attempts has been successful, nor have they resulted in any commercially available product.

However, it has proved to be possible to use as stator winding in a rotating electric machine high-voltage insulating electric conductors with solid insulation, of a similar design as cables for transmission of electric power (e.g. so-called XLPE cables). Such a cable has, inter alia, an outer semiconducting layer, through which the outer potential of the cable is defined. In this way, the cable encloses the electric field inside the winding. In this way, the voltage of the machine may be increased to such levels that it may be directly connected to the power network without intermediate transformers. Thus, for example, the very important advantage is achieved that the conventional transformer may be eliminated.

The insulated conductor or high-voltage cable which is used in the present invention is, as mentioned, flexible and of the kind described in more detail in PCT applications SE97/00874 (WO 97/45919) and SE97/00875 (WO 97/45847). A further description of the insulated conductor or cable is to be found in PCT-applications SE97/00901 (WO 97/45918), SE97/00902 (WO 97/45930) and SE97/00903 (WO 97/45931).

The magnetic core in the machine normally ~~consists of~~has a stator surrounding the rotor of the machine. In such a machine, the winding through the core extends through axial slots in the stator. These slots are generally radially directed, which implies that the distance between the slots increases with the distance from the inner lateral area of the stator. This implies that the magnetic flux density decreases outwards in the stator. At the outer part of the slots, therefore, there is a surplus of core material, which normally consists of laminated sheet iron. This makes the machine unnecessarily bulky and heavy.

This latter is no major problem for small machines, but with increasing size of the machine, the problem is accentuated.

In accordance with the present invention, the winding is in the form of a conductor for high voltage, which implies that the machine becomes relatively large with a large number of winding parts in each slot. Designing a machine for high voltage has been made possible because the conductor according to the invention is ~~provided with means for~~capable of enclosing its electric fields, as ~~indicated in the characterizing portion of claim 1~~described herein.

The problem that a considerable part of the core material is superfluous and entails an unnecessary increase of the volume and weight of the machine is therefore of especially great importance in such a machine designed for high voltage.

SUMMARY OF THE INVENTION

In the light of the above facts, the object of the present invention is to achieve a machine which can directly supply/be supplied with high voltage and hence attempt to minimize the volume and weight of the machine.

~~According to the invention, this has been achieved by designing a machine, of the kind described in the preamble to claim 1, so as to comprise the special features which are described in the characterizing portion of the claim.~~

~~Because of the means~~By enclosing the electric field, ~~and which is~~as described ~~in the characterizing portion~~herein, a machine is achieved which may operate in the high-voltage range and thus be connected to a high-voltage network without being connected to an intermediate transformer.

Because the winding parts exhibit a displacement in relation to one another also in the circumferential direction, which is also described herein, as an additional important ~~characterizing~~ feature, the radial distance between two such parts of the winding may be reduced compared with a situation in which they are only radially displaced. If both winding parts are round and have the same diameter 2r and they are displaced, for example, by a distance r in relation to each other in the circumferential direction, there is room to reduce the radial distance between them by about 14%.

In the context of this application, the expression winding part ~~means~~ is used to refer to the extension of the cable between the axial ends of the stator core of one half-turn of the winding.

Another advantage is that the lateral displacement provides greater flexibility for the location of the parts of the winding in the core, which provides an increased possibility of optimizing the winding based on mechanical, magnetic, thermal and other aspects.

The winding parts in one and the same slot may thus be arranged to be more compact in relation to one another in the radial direction. This provides a possibility of reducing the extent of the slots in the radial direction such that the core may be made correspondingly smaller, with an ensuing lower weight. This results in saving of material and in advantages during manufacture and transport as well as during operation and maintenance.

The possibility of radially compacting the winding, permitted by the lateral displacement of the winding parts, of course becomes greater the more the space, which is made available by the lateral displacement, is utilized for radial compaction. According to

a preferred embodiment of the invention, therefore, the pair of adjacently located winding parts is arranged such that the radially innermost portion of the outer winding part is located radially inside the outermost portion of the inner winding part.

In a preferred embodiment, the displacement increases the further out the winding parts are located. This implies that, during the compaction, the advantage is utilized that increasingly more space is available further out which is not claimed by core material and which may be utilized for increasing displacement in the circumferential direction and hence to reduce the volume to a corresponding extent.

In a preferred embodiment of the invention, the geometry of the slots is such that they also have a directional component in the transverse direction, which constitutes an appropriate adaptation of the shape of the slots to the laterally displaced winding parts.

In a preferred embodiment, this directional component is increasing in that the slot is curved in the transverse direction. This contributes to effectively utilize the outwardly increasing volume which may be utilized between the core material.

The optimal situation in this connection is that each slot in its entirety is curved and that all slots have the same direction of curvature, which thus constitutes an additional preferred embodiment of the invention. An ideal design, from the aspect of volume utilization, is then that all the slots are parallel.

The invention may be realized either by designing it with slots with a radially outwardly increasing width, or with slots with a constant width. In both cases, the slots may advantageously be of the "bicycle chain" type, that is, with alternating wide and narrower parts.

According to a preferred embodiment, the conductor, which ~~comprises the means enclosing~~encloses the electric field, is flexible during at least one full winding turn, which makes possible an advantageous winding process from the point of view of manufacturing engineering.

According to a preferred embodiment, the conductor ~~means enclosing~~ encloses the electric field by having~~comprises~~ an inner semiconducting layer surrounding the conductor, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer.

In an especially preferred embodiment, the layers adhere to one another and have substantially the same coefficient of thermal expansion, whereby it is ensured in an appropriate way that the layers maintain their function when being subjected to the mechanical and thermal stresses occurring during operation.

~~The above-mentioned and other advantageous embodiments of the invented machine are described in the dependent claims referring to claim 1.~~

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in greater detail by the following detailed description of preferred embodiments thereof with reference to the accompanying drawings.

Figure 1 is a schematic view of a stator in an electric machine according to conventional technique;

Figure 2 is a schematic radial section of a stator according to a preferred embodiment of the invention;

Figures 2a, 2b and 3 - 6 show examples of slot shapes, to which the invention is applicable;

Figure 7 is a principle sketch explaining the inventive concept; and

Figure 8 is a radial section through a conductor in the winding according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a principle sketch of how the stator of a conventional electric rotating machine is normally designed. In the core 101 of laminated sheet iron, slots 102 are provided for the windings in the stator. Between each pair of slots, a portion 104 with a trapezoidal cross section is formed, in the following referred to as a stator tooth. The distance d_0 between two slots 102 inside the inner lateral area 103 of the stator is determined by the amount of core material which is required for the magnetic flux density which occurs. With completely radial slots with a constant slot width, as in the figure, the width of the intermediate stator tooth will increase outwardly and provide a surplus of core material. The shaded portion of the tooth denotes the core material which thus becomes "unnecessary", whereas the necessary core material is located between the two dashed lines. The reasoning in this context is to be regarded as a fundamental representation where, in case of different practical applications, modifications from the fundamental representation appear in dependence on different embodiments of the stator of the machine, but where the fundamental aspect of the "usefulness" of the core material is still relevant to a greater or smaller extent. The basic concept of the invention is to eliminate the "unnecessary" core material in various ways, such that the weight and volume of the core may be reduced.

Figure 2 shows a first preferred embodiment of a fundamental design of a stator according to the inventive concept, in which the core 1 is a stator 1 surrounding a rotor (not shown). In the core 1, slots 2 for the windings are provided. The slots 2 are continuously curved, all the slots 2 being curved in the same direction and being parallel. Between each pair of slots 2, a curved tooth 4 is formed with the same principal shape as the slots. Each curved tooth has a width d, that is, the distance between the walls of adjacent slots which is substantially constant and equal to its width d_0 at the inner lateral area 3 of the stator.

The slots are of a so-called bicycle-chain type, in which wide portions alternate with web portions, wherein each of the wider portions accommodates its own cable part. When indicating that the tooth width d is substantially constant, the minor variations, which occur because of these alternating wide portions and web portions, are thus disregarded.

The spiral shape of the slots 2 makes their radial extent smaller than if they had been completely radial with the same number of cable parts in the slots. The shaded field 102 shows the length of the slots in a corresponding radial arrangement of the slots, and (R designates the radial reduction of the stator which could thus be achieved. This makes the stator both smaller and lighter.

Although Figure 2 illustrates a stator according to the invention, where its principles are utilized optimally, there are many alternative possibilities of realizing them. Other considerations during manufacture, design and operation of the machine may lead to embodiments in which the inventive concept is realized in various modified forms and with various degrees of compromise between conflicting considerations.

Figures 2a and 2b illustrate some alternatives for arranging the slots. The circles represent the winding parts. In Fig. 2a, the cable diameter increases outwardly. This is also the case in Fig. 2b, where the slots are extending in a meandering pattern.

In other embodiments, each slot may be curved for part of its extent only, be curved with a changing radius of curvature, or be curved in different directions in meander shape. One slot may also be non-curved with a completely or partially angled relation to the radial direction. Nor does the distance between two slots need to be constant.

Further, Figures 3 to 6 show a few examples of basic shapes of slots, to all of which the invention may be applied. The slots are shown in their basic shape, that is, not curved as in the invention. The slot 2a in Figure 3 has a constant slot width for cable parts where these have the same diameter. The slot 2b in Figure 4 has an outwardly increasing slot width for a winding with coarser winding parts at the farther end. The slots 2c and 2d

in Figures 5 and 6, respectively, show corresponding slots of the "bicycle-chain" type, that is, with alternating wide portions and web portions, the function of the latter being to fix the winding parts radially. The slots may also be designed tapering in the outward direction.

Figure 7 schematically shows two adjacently positioned winding parts displaced according to the invention, and where the intention is to show the principle of the invention.

In Figure 7, two winding parts 5, 6 are arranged in a slot 2 in a stator according to the invention. The arrow A designates the radial direction of the stator, and numeral 106 marks how the outer of the winding parts, 6, would be located if it were located completely radially outside the inner winding part 5 in a slot 102, that is, in conventional manner. For the sake of clarity, the winding parts are shown to be tangent to each other, which, of course, is not always the case. However, the representation is, in principle, relevant also when this is not the case.

The outer winding part 6 is displaced across the radial direction by a distance a compared to the conventionally placed winding part 106. This displacement has allowed space to displace the winding part 6 also in the radial direction by a distance b compared to the conventionally placed winding part 106.

With the radii r_1 and r_2 of the two winding parts, distance $b = r_1 + r_2 - \sqrt{[(r_1 + r_2)^2 - a^2]}$ and if $r_1 = r_2 = r$, this is simplified to $b = 2r - \sqrt{[4r^2 - a^2]}$. If the lateral displacement $a = r$, the radial displacement $b = r(2 - \sqrt{3}) = 0.27\ r$, that is, it means in this case a reduction of the radial space, required by the outer winding part, by about 14 %.

Finally, Figure 8 shows a cross section of a cable which is particularly suitable for use as a winding in the stator according to the invention. The cable 6 ~~comprises~~ has at least one current-carrying conductor 31 of, for example, copper surrounded by a first semiconducting layer 32. Around this first semiconducting layer there is arranged an insulating layer 33, for example an XLPE insulation, and around this layer there is arranged, in turn, a second semiconducting layer 34. The electric conductor may ~~consist~~ have ~~of~~ a number of parts 31. The three layers are designed so as to adhere to one another also when the cable is bent. The cable shown is flexible and this property is maintained in the cable during its service life. The illustrated cable also differs from a conventional high-voltage cable in that the outer mechanically protecting casing and the metal screen which normally surrounds it are eliminated.

CLAIMS

1. A rotating electric machine comprising a magnetic core (1) with a centre axis defining an axial direction, a radial direction and a circumferential direction of the core, said core (1) exhibiting a plurality of slots (2), each slot (2) defining a longitudinal direction comprising an axial directional component and a transverse direction comprising a radial directional component wherein the directions of the slot (2) are defined by is centre plane between the walls of the slot (2), and the slot (2) has a width which is defined as the distance between its walls, an electric winding with a plurality of winding parts (5, 6), extending in the longitudinal direction, being arranged in each slot (2), at least some winding slots (5, 6) in at least some slots being located radially displaced in relation to one another, characterized in that the winding comprises an electric conductor (31) for high voltage, said conductor (31), during at least one full winding turn, being provided with means (32, 33, 34) for essentially enclosing its electric fields, and that at least one pair of adjacently located winding parts (5, 6) in a slot (2) are displaced in the circumferential direction relative to each other.

2. A rotating electric machine according to claim 1, in which, in said pair of adjacently located winding parts (5, 6), the radially innermost part of the outer winding part (6) is located radially inside the outermost part of the inner winding part (5).

3. A rotating electric machine according to claim 1 or 2, in which at least two pairs of winding parts (5, 6) in the slot are displaced in the circumferential direction in relation to each other and wherein the displacement is greater the farther outwards, in the radial direction, the winding parts (5, 6) are located.

4. A rotating electric machine according to any of claim 1 or 2, in which at least some slot (2) along at least part of its transverse direction has a directional component in the circumferential direction.

5. A rotating electric machine according to claim 4, in which at least some slot (2) is at least partially curved in the transverse direction.

6. A rotating electric machine according to claim 5, in which each slot (2) is curved along its whole transverse direction and all the slots (2) have the same radius of curvature.

7. A rotating electric machine according to any of claims 1-6, in which all the slots (2) are parallel in both the longitudinal direction and the transverse direction.

8. A rotating electric machine according to any of claims 1-6, in which at least some slot (2b, 2d) has an increasing width outwards along the transverse direction.

9. A rotating electric machine according to any of claims 1-7, in which at least some slot (2a, 2c) has a constant width in the transverse direction.

10. A rotating electric machine according to any of claims 1-6, in which at least some slot (2c, 2d) in the transverse direction has alternating portions with a larger and smaller width.

11. A rotating electric machine according to claims 10, in which the portions with a larger width have a varying width.

12. A rotating electric machine according to claims 10, in which the portions with a larger width have mutually the same width.

13. A rotating electric machine according to any of claims 1-12, in which the conductor, during at least one full winding turn, is flexible.

14. A rotating electric machine according to any of claims 1-13, in which said means comprise an inner semiconducting layer (32) surrounding the conductor, an insulating layer (33) surrounding the semiconducting layer (32), and an outer semiconducting layer (34) surrounding the insulating layer (33).

15. A rotating electric machine according to claim 14, in which each semiconducting layer (32, 34) constitutes essentially an equipotential surface.

16. A rotating electric machine according to claim 15, in which the layers (32, 33, 34) adhere to one another along the whole winding, and that said semiconducting layers (32, 34) have substantially the same coefficient of thermal conductivity as the intermediate insulating layer (33).

17. A rotating electric machine according to any of claims 1-16, in which said means (32, 33, 34) are dimensioned to allow a voltage in the conductor which is greater than 72 kV. --

~~ABSTRACT~~

~~The invention relates to a rotating electric machine with a magnetic core (1). The core (1) is provided with slots (2) for a winding.~~

~~According to the invention, the winding comprises an electric conductor for high voltage. During at least one full winding turn, the winding is provided with means for essentially enclosing its electric fields. Further, according to the invention, the winding parts in a slot (2) are displaced in the circumferential direction relative to each other.~~

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SUBSTITUTE SPECIFICATION

9847-0050-6X PCT

ENKEL 8337

TITLE OF THE INVENTION

A ROTATING ELECTRIC MACHINE WITH A MAGNETIC CORE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a rotating electric machine. The rotating electric machines which are referred to in this context are synchronous machines, which are substantially used as generators for connection to distribution and transmission networks, commonly called power networks. The synchronous machines are also used as motors as well as for phase compensation and voltage control, and, in that case, as mechanically idling machines. This technical field also includes normal asynchronous machines, double-fed machines, AC-machines, asynchronous converter cascades, external pole machines and synchronous flux machines. These machines are intended to be used at high voltages, by which are meant here electric voltages which primarily exceed 10 kV. One typical field of operation for such a rotating machine may be 36 - 800 kV, and preferably 72.5 - 800 kV.

Discussion of the Background

Rotating electric machines have conventionally been designed for voltages within the interval 6 - 30 kV, whereby 30 kV has normally been considered to be an upper limit. In the generator case, this normally implies that a generator must be connected to the power network over a transformer which steps up the voltage to the level of the network, which lies within the range of about 130 - 400 kV.

Over the years, various attempts have been made to develop special synchronous machines, preferably generators, for high voltages. Examples of this are described, inter alia, in "Electrical World", October 15, 1932, pages 524-525, the article "Water-and-Oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pages 6-8, and patent publications US 4,424,244 and SU 955 369. However, none of these attempts has been successful, nor have they resulted in any commercially available product.

However, it has proved to be possible to use as stator winding in a rotating electric machine high-voltage insulating electric conductors with solid insulation, of a similar design as cables for transmission of electric power (e.g. so-called XLPE cables). Such a cable has, inter alia, an outer semiconducting layer, through which the outer potential of the cable is defined. In this way, the cable encloses the electric field inside the winding. In this way, the voltage of the machine may be increased to such levels that it may be directly connected to the power network without intermediate transformers. Thus, for example, the very important advantage is achieved that the conventional transformer may be eliminated.

The insulated conductor or high-voltage cable which is used in the present invention is, as mentioned, flexible and of the kind described in more detail in PCT applications SE97/00874 (WO 97/45919) and SE97/00875 (WO 97/45847). A further description of the insulated conductor or cable is to be found in PCT-applications SE97/00901 (WO 97/45918), SE97/00902 (WO 97/45930) and SE97/00903 (WO 97/45931).

The magnetic core in the machine normally has a stator surrounding the rotor of the machine. In such a machine, the winding through the core extends through axial slots in the stator. These slots are generally radially directed, which implies that the distance between the slots increases with the distance from the inner lateral area of the stator. This implies that the magnetic flux density decreases outwards in the stator. At the outer part of the slots, therefore, there is a surplus of core material, which normally consists of laminated sheet iron. This makes the machine unnecessarily bulky and heavy.

This latter is no major problem for small machines, but with increasing size of the machine, the problem is accentuated.

In accordance with the present invention, the winding is in the form of a conductor for high voltage, which implies that the machine becomes relatively large with a large number of winding parts in each slot. Designing a machine for high voltage has been made possible because the conductor according to the invention is capable of enclosing its electric fields, as described herein.

The problem that a considerable part of the core material is superfluous and entails an unnecessary increase of the volume and weight of the machine is therefore of especially great importance in such a machine designed for high voltage.

SUMMARY OF THE INVENTION

In the light of the above facts, the object of the present invention is to achieve a machine which can directly supply/be supplied with high voltage and hence attempt to minimize the volume and weight of the machine.

By enclosing the electric field, as described herein, a machine is achieved which may operate in the high-voltage range and thus be connected to a high-voltage network without being connected to an intermediate transformer.

Because the winding parts exhibit a displacement in relation to one another also in the circumferential direction, which is also described herein, as an additional important feature, the radial distance between two such parts of the winding may be reduced compared with a situation in which they are only radially displaced. If both winding parts are round and have the same diameter 2r and they are displaced, for example, by a distance r in relation to each other in the circumferential direction, there is room to reduce the radial distance between them by about 14%.

In the context of this application, the expression winding part is used to refer to the extension of the cable between the axial ends of the stator core of one half-turn of the winding.

Another advantage is that the lateral displacement provides greater flexibility for the location of the parts of the winding in the core, which provides an increased possibility of optimizing the winding based on mechanical, magnetic, thermal and other aspects.

The winding parts in one and the same slot may thus be arranged to be more compact in relation to one another in the radial direction. This provides a possibility of reducing the extent of the slots in the radial direction such that the core may be made correspondingly smaller, with an ensuing lower weight. This results in saving of material and in advantages during manufacture and transport as well as during operation and maintenance.

The possibility of radially compacting the winding, permitted by the lateral displacement of the winding parts, of course becomes greater the more the space, which is made available by the lateral displacement, is utilized for radial compaction. According to a preferred embodiment of the invention, therefore, the pair of adjacently located winding parts is arranged such that the radially innermost portion of the outer winding part is located radially inside the outermost portion of the inner winding part.

In a preferred embodiment, the displacement increases the further out the winding parts are located. This implies that, during the compaction, the advantage is utilized that

increasingly more space is available further out which is not claimed by core material and which may be utilized for increasing displacement in the circumferential direction and hence to reduce the volume to a corresponding extent.

In a preferred embodiment of the invention, the geometry of the slots is such that they also have a directional component in the transverse direction, which constitutes an appropriate adaptation of the shape of the slots to the laterally displaced winding parts.

In a preferred embodiment, this directional component is increasing in that the slot is curved in the transverse direction. This contributes to effectively utilize the outwardly increasing volume which may be utilized between the core material.

The optimal situation in this connection is that each slot in its entirety is curved and that all slots have the same direction of curvature, which thus constitutes an additional preferred embodiment of the invention. An ideal design, from the aspect of volume utilization, is then that all the slots are parallel.

The invention may be realized either by designing it with slots with a radially outwardly increasing width, or with slots with a constant width. In both cases, the slots may advantageously be of the "bicycle chain" type, that is, with alternating wide and narrower parts.

According to a preferred embodiment, the conductor, which encloses the electric field, is flexible during at least one full winding turn, which makes possible an advantageous winding process from the point of view of manufacturing engineering.

According to a preferred embodiment, the conductor encloses the electric field by having an inner semiconducting layer surrounding the conductor, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer.

In an especially preferred embodiment, the layers adhere to one another and have substantially the same coefficient of thermal expansion, whereby it is ensured in an appropriate way that the layers maintain their function when being subjected to the mechanical and thermal stresses occurring during operation.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in greater detail by the following detailed description of preferred embodiments thereof with reference to the accompanying drawings.

Figure 1 is a schematic view of a stator in an electric machine according to conventional technique;

Figure 2 is a schematic radial section of a stator according to a preferred embodiment of the invention;

Figures 2a, 2b and 3 - 6 show examples of slot shapes, to which the invention is applicable;

Figure 7 is a principle sketch explaining the inventive concept; and

Figure 8 is a radial section through a conductor in the winding according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a principle sketch of how the stator of a conventional electric rotating machine is normally designed. In the core 101 of laminated sheet iron, slots 102 are provided for the windings in the stator. Between each pair of slots, a portion 104 with a trapezoidal cross section is formed, in the following referred to as a stator tooth. The distance d_0 between two slots 102 inside the inner lateral area 103 of the stator is determined by the amount of core material which is required for the magnetic flux density which occurs. With completely radial slots with a constant slot width, as in the figure, the width of the intermediate stator tooth will increase outwardly and provide a surplus of core material. The shaded portion of the tooth denotes the core material which thus becomes "unnecessary", whereas the necessary core material is located between the two dashed lines. The reasoning in this context is to be regarded as a fundamental representation where, in case of different practical applications, modifications from the fundamental representation appear in dependence on different embodiments of the stator of the machine, but where the fundamental aspect of the "usefulness" of the core material is still relevant to a greater or smaller extent. The basic concept of the invention is to eliminate the "unnecessary" core material in various ways, such that the weight and volume of the core may be reduced.

Figure 2 shows a first preferred embodiment of a fundamental design of a stator according to the inventive concept, in which the core 1 is a stator 1 surrounding a rotor (not shown). In the core 1, slots 2 for the windings are provided. The slots 2 are continuously curved, all the slots 2 being curved in the same direction and being parallel. Between each pair of slots 2, a curved tooth 4 is formed with the same principal shape as the slots. Each curved tooth has a width d, that is, the distance between the walls of adjacent slots which is substantially constant and equal to its width d_0 at the inner lateral area 3 of the stator.

The slots are of a so-called bicycle-chain type, in which wide portions alternate with web portions, wherein each of the wider portions accommodates its own cable part. When indicating that the tooth width d is substantially constant, the minor variations, which occur because of these alternating wide portions and web portions, are thus disregarded.

The spiral shape of the slots 2 makes their radial extent smaller than if they had been completely radial with the same number of cable parts in the slots. The shaded field 102 shows the length of the slots in a corresponding radial arrangement of the slots, and (R designates the radial reduction of the stator which could thus be achieved. This makes the stator both smaller and lighter.

Although Figure 2 illustrates a stator according to the invention, where its principles are utilized optimally, there are many alternative possibilities of realizing them. Other considerations during manufacture, design and operation of the machine may lead to embodiments in which the inventive concept is realized in various modified forms and with various degrees of compromise between conflicting considerations.

Figures 2a and 2b illustrate some alternatives for arranging the slots. The circles represent the winding parts. In Fig. 2a, the cable diameter increases outwardly. This is also the case in Fig. 2b, where the slots are extending in a meandering pattern.

In other embodiments, each slot may be curved for part of its extent only, be curved with a changing radius of curvature, or be curved in different directions in meander shape. One slot may also be non-curved with a completely or partially angled relation to the radial direction. Nor does the distance between two slots need to be constant.

Further, Figures 3 to 6 show a few examples of basic shapes of slots, to all of which the invention may be applied. The slots are shown in their basic shape, that is, not curved as in the invention. The slot 2a in Figure 3 has a constant slot width for cable parts where these have the same diameter. The slot 2b in Figure 4 has an outwardly increasing slot width for a winding with coarser winding parts at the farther end. The slots 2c and 2d in Figures 5 and 6, respectively, show corresponding slots of the "bicycle-chain" type, that is, with alternating wide portions and web portions, the function of the latter being to fix the winding parts radially. The slots may also be designed tapering in the outward direction.

Figure 7 schematically shows two adjacently positioned winding parts displaced according to the invention, and where the intention is to show the principle of the invention.

In Figure 7, two winding parts 5, 6 are arranged in a slot 2 in a stator according to the invention. The arrow A designates the radial direction of the stator, and numeral 106 marks how the outer of the winding parts, 6, would be located if it were located completely radially outside the inner winding part 5 in a slot 102, that is, in conventional manner. For the sake of clarity, the winding parts are shown to be tangent to each other, which, of course, is not always the case. However, the representation is, in principle, relevant also when this is not the case.

The outer winding part 6 is displaced across the radial direction by a distance a compared to the conventionally placed winding part 106. This displacement has allowed space to displace the winding part 6 also in the radial direction by a distance b compared to the conventionally placed winding part 106.

With the radii r_1 and r_2 of the two winding parts, distance $b = r_1 + r_2 - \sqrt{[(r_1 + r_2)^2 - a^2]}$ and if $r_1 = r_2 = r$, this is simplified to $b = 2r - \sqrt{[4 r^2 - a^2]}$. If the lateral displacement $a = r$, the radial displacement $b = r(2 - \sqrt{3}) = 0.27 r$, that is, it means in this case a reduction of the radial space, required by the outer winding part, by about 14 %.

Finally, Figure 8 shows a cross section of a cable which is particularly suitable for use as a winding in the stator according to the invention. The cable 6 has at least one current-carrying conductor 31 of, for example, copper surrounded by a first semiconducting layer 32. Around this first semiconducting layer there is arranged an insulating layer 33, for example an XLPE insulation, and around this layer there is arranged, in turn, a second semiconducting layer 34. The electric conductor may have a number of parts 31. The three layers are designed so as to adhere to one another also when the cable is bent. The cable shown is flexible and this property is maintained in the cable during its service life. The illustrated cable also differs from a conventional high-voltage cable in that the outer mechanically protecting casing and the metal screen which normally surrounds it are eliminated.

CLAIMS

1. A rotating electric machine comprising a magnetic core (1) with a centre axis defining an axial direction, a radial direction and a circumferential direction of the core, said core (1) exhibiting a plurality of slots (2), each slot (2) defining a longitudinal direction comprising an axial directional component and a transverse direction comprising a radial directional component wherein the directions of the slot (2) are defined by is centre plane between the walls of the slot (2), and the slot (2) has a width which is defined as the distance between its walls, an electric winding with a plurality of winding parts (5, 6), extending in the longitudinal direction, being arranged in each slot (2), at least some winding slots (5, 6) in at least some slots being located radially displaced in relation to one another, characterized in that the winding comprises an electric conductor (31) for high voltage, said conductor (31), during at least one full winding turn, being provided with means (32, 33, 34) for essentially enclosing its electric fields, and that at least one pair of adjacently located winding parts (5, 6) in a slot (2) are displaced in the circumferential direction relative to each other.

2. A rotating electric machine according to claim 1, in which, in said pair of adjacently located winding parts (5, 6), the radially innermost part of the outer winding part (6) is located radially inside the outermost part of the inner winding part (5).

3. A rotating electric machine according to claim 1 or 2, in which at least two pairs of winding parts (5, 6) in the slot are displaced in the circumferential direction in relation to each other and wherein the displacement is greater the farther outwards, in the radial direction, the winding parts (5, 6) are located.

4. A rotating electric machine according to any of claim 1 or 2, in which at least some slot (2) along at least part of its transverse direction has a directional component in the circumferential direction.

5. A rotating electric machine according to claim 4, in which at least some slot (2) is at least partially curved in the transverse direction.

6. A rotating electric machine according to claim 5, in which each slot (2) is curved along its whole transverse direction and all the slots (2) have the same radius of curvature.

7. A rotating electric machine according to any of claims 1-6, in which all the slots (2) are parallel in both the longitudinal direction and the transverse direction.

8. A rotating electric machine according to any of claims 1-6, in which at least some slot (2b, 2d) has an increasing width outwards along the transverse direction.

9. A rotating electric machine according to any of claims 1-7, in which at least some slot (2a, 2c) has a constant width in the transverse direction.

10. A rotating electric machine according to any of claims 1-6, in which at least some slot (2c, 2d) in the transverse direction has alternating portions with a larger and smaller width.

11. A rotating electric machine according to claims 10, in which the portions with a larger width have a varying width.

12. A rotating electric machine according to claims 10, in which the portions with a larger width have mutually the same width.

13. A rotating electric machine according to any of claims 1-12, in which the conductor, during at least one full winding turn, is flexible.

14. A rotating electric machine according to any of claims 1-13, in which said means comprise an inner semiconducting layer (32) surrounding the conductor, an insulating layer (33) surrounding the semiconducting layer (32), and an outer semiconducting layer (34) surrounding the insulating layer (33).

15. A rotating electric machine according to claim 14, in which each semiconducting layer (32, 34) constitutes essentially an equipotential surface.

16. A rotating electric machine according to claim 15, in which the layers (32, 33, 34) adhere to one another along the whole winding, and that said semiconducting layers (32, 34) have substantially the same coefficient of thermal conductivity as the intermediate insulating layer (33).

17. A rotating electric machine according to any of claims 1-16, in which said means (32, 33, 34) are dimensioned to allow a voltage in the conductor which is greater than 72 kV.

A ROTATING ELECTRIC MACHINE WITH A MAGNETIC CORE

The present invention relates to a rotating electric machine of the kind described in the preamble to claim 1.

The rotating electric machines which are referred to in this context comprises synchronous machines, which are substantially used as generators for connection to distribution and transmission networks, commonly called power networks. The synchronous machines are also used as motors as well as for phase compensation and voltage control, and, in that case, as mechanically idling machines. This technical field also comprises normal asynchronous machines, double-fed machines, AC-machines, asynchronous converter cascades, external pole machines and synchronous flux machines. These machines are intended to be used at high voltages, by which are meant here electric voltages which primarily exceed 10 kV. One typical field of operation for such a rotating machine may be 36 - 800 kV, and preferably 72.5 - 800 kV.

Rotating electric machines have conventionally been designed for voltages within the interval 6 - 30 kV, whereby 30 kV has normally been considered to be an upper limit. In the generator case, this normally implies that a generator must be connected to the power network over a transformer which steps up the voltage to the level of the network, which lies within the range of about 130 - 400 kV.

Over the years, various attempts have been made to develop special synchronous machines, preferably generators, for high voltages. Examples of this are described, inter alia, in "Electrical World", October 15, 1932, pages 524-525, the article "Water-and-Oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pages 6-8, and patent publications US 4,424,244 and SU 955 369. However, none of these attempts has been successful, nor have they resulted in any commercially available product.

However, it has proved to be possible to use as stator winding in a rotating electric machine high-voltage insulating electric conductors with solid insulation, of a similar design as cables for transmission of electric power (e.g. so-called XLPE cables). Such a cable has, inter alia, an outer semiconducting layer, through

which the outer potential of the cable is defined. In this way, the cable encloses the electric field inside the winding. In this way, the voltage of the machine may be increased to such levels that it may be directly connected to the power network without intermediate transformers. Thus, for example, the very important advantage is achieved that the conventional transformer may be eliminated.

The insulated conductor or high-voltage cable which is used in the present invention is, as mentioned, flexible and of the kind described in more detail in PCT applications SE97/00874 (WO 97/45919) and SE97/00875 (WO 97/45847). A further description of the insulated conductor or cable is to be found in PCT-applications SE97/00901 (WO 97/45918), SE97/00902 (WO 97/45930) and SE97/00903 (WO 97/45931).

The magnetic core in the machine normally consists of a stator surrounding the rotor of the machine. In such a machine, the winding through the core extends through axial slots in the stator. These slots are generally radially directed, which implies that the distance between the slots increases with the distance from the inner lateral area of the stator. This implies that the magnetic flux density decreases outwards in the stator. At the outer part of the slots, therefore, there is a surplus of core material, which normally consists of laminated sheet iron. This makes the machine unnecessarily bulky and heavy.

This latter is no major problem for small machines, but with increasing size of the machine, the problem is accentuated.

In accordance with the present invention, the winding is in the form of a conductor for high voltage, which implies that the machine becomes relatively large with a large number of winding parts in each slot. Designing a machine for high voltage has been made possible because the conductor according to the invention is provided with means for enclosing its electric fields, as indicated in the characterizing portion of claim 1.

The problem that a considerable part of the core material is superfluous and entails an unnecessary increase of the volume and weight of the machine is therefore of especially great importance in such a machine designed for high voltage.

In the light of the above facts, the object of the present invention is to achieve a machine which can directly supply/be supplied with high voltage and hence attempt to minimize the volume and weight of the machine.

According to the invention, this has been achieved by designing a machine, of the kind described in the preamble to claim 1, so as to comprise the special features which are described in the characterizing portion of the claim.

Because of the means enclosing the electric field, and which is described in the characterizing portion, a machine is achieved which may operate in the high-voltage range and thus be connected to a high-voltage network without being connected to an intermediate transformer.

Because the winding parts exhibit a displacement in relation to one another also in the circumferential direction, which is described as an additional important characterizing feature, the radial distance between two such parts of the winding may be reduced compared with a situation in which they are only radially displaced. If both winding parts are round and have the same diameter 2r and they are displaced, for example, by a distance r in relation to each other in the circumferential direction, there is room to reduce the radial distance between them by about 14%.

In the context of this application, the expression winding part means the extension of the cable between the axial ends of the stator core of one half-turn of the winding.

Another advantage is that the lateral displacement provides greater flexibility for the location of the parts of the winding in the core, which provides an increased possibility of optimizing the winding based on mechanical, magnetic, thermal and other aspects.

The winding parts in one and the same slot may thus be arranged to be more compact in relation to one another in the radial direction. This provides a possibility of reducing the extent of the slots in the radial direction such that the core may be made correspondingly smaller, with an ensuing lower weight. This results in saving of material and in advantages during manufacture and transport as well as during operation and maintenance.

The possibility of radially compacting the winding, permitted by the lateral displacement of the winding parts, of course becomes greater the more the space, which is made available by the lateral displacement, is utilized for radial compaction. According to a preferred embodiment of the invention, therefore, the pair of adjacently located winding parts is arranged such that the radially innermost portion of the outer winding part is located radially inside the outermost portion of the inner winding part.

In a preferred embodiment, the displacement increases the further out the winding parts are located. This implies that, during the compaction, the advantage is utilized that increasingly more space is available further out which is not claimed by core material and which may be utilized for increasing displacement in the circumferential direction and hence to reduce the volume to a corresponding extent.

In a preferred embodiment of the invention, the geometry of the slots is such that they also have a directional component in the transverse direction, which constitutes an appropriate adaptation of the shape of the slots to the laterally displaced winding parts.

In a preferred embodiment, this directional component is increasing in that the slot is curved in the transverse direction. This contributes to effectively utilize the outwardly increasing volume which may be utilized between the core material.

The optimal situation in this connection is that each slot in its entirety is curved and that all slots have the same direction of curvature, which thus constitutes an additional preferred embodiment of the invention. An ideal design, from the aspect of volume utilization, is then that all the slots are parallel.

The invention may be realized either by designing it with slots with a radially outwardly increasing width, or with slots with a constant width. In both cases, the slots may advantageously be of the "bicycle chain" type, that is, with alternating wide and narrower parts.

According to a preferred embodiment, the conductor, which comprises the means enclosing the electric field, is flexible during at least one full winding turn, which makes possible an advantageous winding process from the point of view of manufacturing engineering.

According to a preferred embodiment, the means enclosing the electric field comprises an inner semiconducting layer surrounding the conductor, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer.

In an especially preferred embodiment, the layers adhere to one another and have substantially the same coefficient of thermal expansion, whereby it is ensured in an appropriate way that the layers maintain their function when being subjected to the mechanical and thermal stresses occurring during operation.

The above-mentioned and other advantageous embodiments of the invented machine are described in the dependent claims referring to claim 1.

The invention will be described in greater detail by the following detailed description of preferred embodiments thereof with reference to the accompanying drawings.

Figure 1 is a schematic view of a stator in an electric machine according to conventional technique;

Figure 2 is a schematic radial section of a stator according to a preferred embodiment of the invention;

Figures 2a, 2b and 3 - 6 show examples of slot shapes, to which the invention is applicable;

Figure 7 is a principle sketch explaining the inventive concept; and

Figure 8 is a radial section through a conductor in the winding according to the invention.

Figure 1 shows a principle sketch of how the stator of a conventional electric rotating machine is normally designed. In the core 101 of laminated sheet iron, slots 102 are provided for the windings in the stator. Between each pair of slots, a portion 104 with a trapezoidal cross section is formed, in the following referred to as a stator tooth. The distance d_0 between two slots 102 inside the inner lateral area 103 of the stator is determined by the amount of core material which is required for the magnetic flux density which occurs. With completely radial slots with a constant slot width, as in the figure, the width of the intermediate stator tooth will increase outwardly and provide a surplus of core material. The shaded portion of the tooth denotes the core material which thus becomes "unnecessary",

whereas the necessary core material is located between the two dashed lines. The reasoning in this context is to be regarded as a fundamental representation where, in case of different practical applications, modifications from the fundamental representation appear in dependence on different embodiments of the stator of the machine, but where the fundamental aspect of the "usefulness" of the core material is still relevant to a greater or smaller extent. The basic concept of the invention is to eliminate the "unnecessary" core material in various ways, such that the weight and volume of the core may be reduced.

Figure 2 shows a first preferred embodiment of a fundamental design of a stator according to the inventive concept, in which the core 1 is a stator 1 surrounding a rotor (not shown). In the core 1, slots 2 for the windings are provided. The slots 2 are continuously curved, all the slots 2 being curved in the same direction and being parallel. Between each pair of slots 2, a curved tooth 4 is formed with the same principal shape as the slots. Each curved tooth has a width d, that is, the distance between the walls of adjacent slots which is substantially constant and equal to its width d_0 at the inner lateral area 3 of the stator.

The slots are of a so-called bicycle-chain type, in which wide portions alternate with web portions, wherein each of the wider portions accommodates its own cable part. When indicating that the tooth width d is substantially constant, the minor variations, which occur because of these alternating wide portions and web portions, are thus disregarded.

The spiral shape of the slots 2 makes their radial extent smaller than if they had been completely radial with the same number of cable parts in the slots. The shaded field 102 shows the length of the slots in a corresponding radial arrangement of the slots, and (R designates the radial reduction of the stator which could thus be achieved. This makes the stator both smaller and lighter.

Although Figure 2 illustrates a stator according to the invention, where its principles are utilized optimally, there are many alternative possibilities of realizing them. Other considerations during manufacture, design and operation of the machine may lead to embodiments in which the inventive concept is realized in various modified forms and with various degrees of compromise between conflicting considerations.

Figures 2a and 2b illustrate some alternatives for arranging the slots. The circles represent the winding parts. In Fig. 2a, the cable diameter increases outwardly. This is also the case in Fig. 2b, where the slots are extending in a meandering pattern.

In other embodiments, each slot may be curved for part of its extent only, be curved with a changing radius of curvature, or be curved in different directions in meander shape. One slot may also be non-curved with a completely or partially angled relation to the radial direction. Nor does the distance between two slots need to be constant.

Further, Figures 3 to 6 show a few examples of basic shapes of slots, to all of which the invention may be applied. The slots are shown in their basic shape, that is, not curved as in the invention. The slot 2a in Figure 3 has a constant slot width for cable parts where these have the same diameter. The slot 2b in Figure 4 has an outwardly increasing slot width for a winding with coarser winding parts at the farther end. The slots 2c and 2d in Figures 5 and 6, respectively, show corresponding slots of the "bicycle-chain" type, that is, with alternating wide portions and web portions, the function of the latter being to fix the winding parts radially. The slots may also be designed tapering in the outward direction.

Figure 7 schematically shows two adjacently positioned winding parts displaced according to the invention, and where the intention is to show the principle of the invention.

In Figure 7, two winding parts 5, 6 are arranged in a slot 2 in a stator according to the invention. The arrow A designates the radial direction of the stator, and numeral 106 marks how the outer of the winding parts, 6, would be located if it were located completely radially outside the inner winding part 5 in a slot 102, that is, in conventional manner. For the sake of clarity, the winding parts are shown to be tangent to each other, which, of course, is not always the case. However, the representation is, in principle, relevant also when this is not the case.

The outer winding part 6 is displaced across the radial direction by a distance a compared to the conventionally placed winding part 106. This displacement has allowed space to displace the winding part 6 also in the radial direction by a distance b compared to the conventionally placed winding part 106.

With the radii r_1 and r_2 of the two winding parts, distance $b = r_1 + r_2 - \sqrt{(r_1 + r_2)^2 - a^2}$ and if $r_1 = r_2 = r$, this is simplified to $b = 2r - \sqrt{4r^2 - a^2}$. If the lateral displacement $a = r$, the radial displacement $b = r(2 - \sqrt{3}) = 0.27\ r$, that is, it means in this case a reduction of the radial space, required by the outer winding part, by about 14 %.

Finally, Figure 8 shows a cross section of a cable which is particularly suitable for use as a winding in the stator according to the invention. The cable 6 comprises at least one current-carrying conductor 31 of, for example, copper surrounded by a first semiconducting layer 32. Around this first semiconducting layer there is arranged an insulating layer 33, for example an XLPE insulation, and around this layer there is arranged, in turn, a second semiconducting layer 34. The electric conductor may consist of a number of parts 31. The three layers are designed so as to adhere to one another also when the cable is bent. The cable shown is flexible and this property is maintained in the cable during its service life. The illustrated cable also differs from a conventional high-voltage cable in that the outer mechanically protecting casing and the metal screen which normally surrounds it are eliminated.

CLAIMS

1. A rotating electric machine comprising a magnetic core (1) with a centre axis defining an axial direction, a radial direction and a circumferential direction of the core, said core (1) exhibiting a plurality of slots (2), each slot (2) defining a longitudinal direction comprising an axial directional component and a transverse direction comprising a radial directional component wherein the directions of the slot (2) are defined by is centre plane between the walls of the slot (2), and the slot (2) has a width which is defined as the distance between its walls, an electric winding with a plurality of winding parts (5, 6), extending in the longitudinal direction, being arranged in each slot (2), at least some winding slots (5, 6) in at least some slots being located radially displaced in relation to one another, characterized in that the winding comprises an electric conductor (31) for high voltage, said conductor (31), during at least one full winding turn, being provided with means (32, 33, 34) for essentially enclosing its electric fields, and that at least one pair of adjacently located winding parts (5, 6) in a slot (2) are displaced in the circumferential direction relative to each other.

2. A rotating electric machine according to claim 1, in which, in said pair of adjacently located winding parts (5, 6), the radially innermost part of the outer winding part (6) is located radially inside the outermost part of the inner winding part (5).

3. A rotating electric machine according to claim 1 or 2, in which at least two pairs of winding parts (5, 6) in the slot are displaced in the circumferential direction in relation to each other and wherein the displacement is greater the farther outwards, in the radial direction, the winding parts (5, 6) are located.

4. A rotating electric machine according to any of claim 1 or 2, in which at least some slot (2) along at least part of its transverse direction has a directional component in the circumferential direction.

5. A rotating electric machine according to claim 4, in which at least some slot (2) is at least partially curved in the transverse direction.

6. A rotating electric machine according to claim 5, in which each slot (2) is curved along its whole transverse direction and all the slots (2) have the same radius of curvature.

7. A rotating electric machine according to any of claims 1-6, in which all the slots (2) are parallel in both the longitudinal direction and the transverse direction.

8. A rotating electric machine according to any of claims 1-6, in which at least some slot (2b, 2d) has an increasing width outwards along the transverse direction.

9. A rotating electric machine according to any of claims 1-7, in which at least some slot (2a, 2c) has a constant width in the transverse direction.

10. A rotating electric machine according to any of claims 1-6, in which at least some slot (2c, 2d) in the transverse direction has alternating portions with a larger and smaller width.

11. A rotating electric machine according to claims 10, in which the portions with a larger width have a varying width.

12. A rotating electric machine according to claims 10, in which the portions with a larger width have mutually the same width.

13. A rotating electric machine according to any of claims 1-12, in which the conductor, during at least one full winding turn, is flexible.

14. A rotating electric machine according to any of claims 1-13, in which said means comprise an inner semiconducting layer (32) surrounding the conductor,

an insulating layer (33) surrounding the semiconducting layer (32), and an outer semiconducting layer (34) surrounding the insulating layer (33).

15. A rotating electric machine according to claim 14, in which each semiconducting layer (32, 34) constitutes essentially an equipotential surface.

16. A rotating electric machine according to claim 15, in which the layers (32, 33, 34) adhere to one another along the whole winding, and that said semiconducting layers (32, 34) have substantially the same coefficient of thermal conductivity as the intermediate insulating layer (33).

17. A rotating electric machine according to any of claims 1-16, in which said means (32, 33, 34) are dimensioned to allow a voltage in the conductor which is greater than 72 kV.

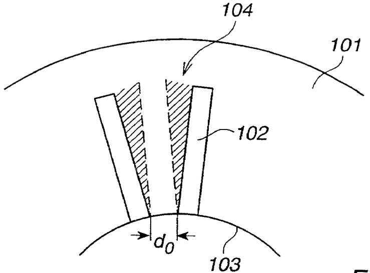

Fig. 1

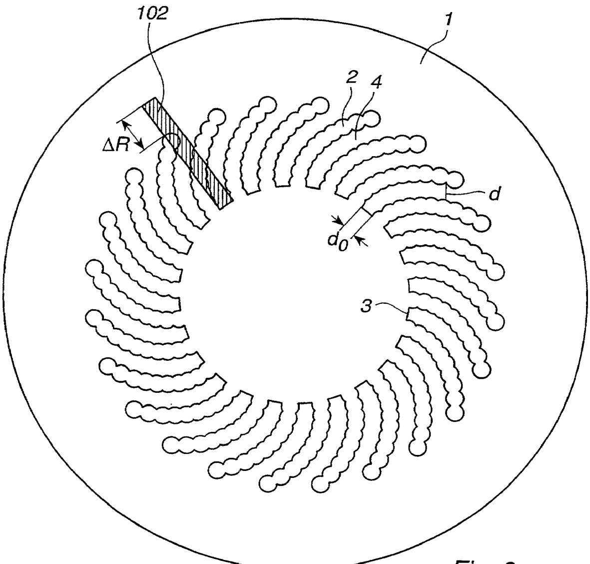

Fig. 2

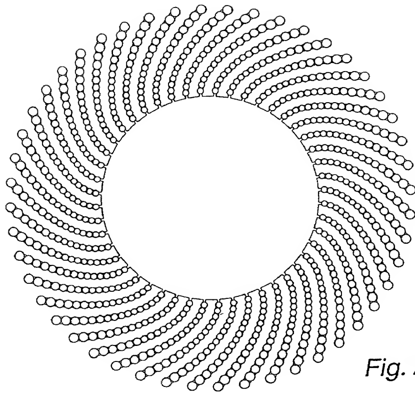

Fig. 2 a

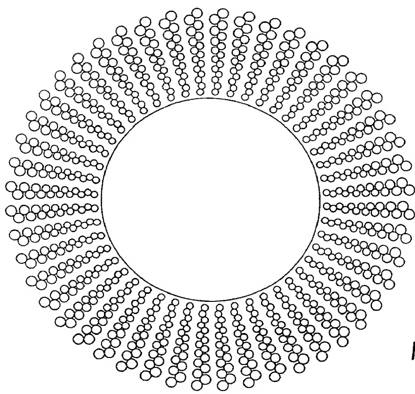

Fig. 2 b

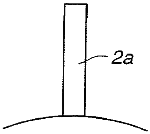

Fig. 3

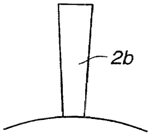

Fig. 4

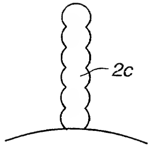

Fig. 5

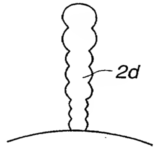

Fig. 6

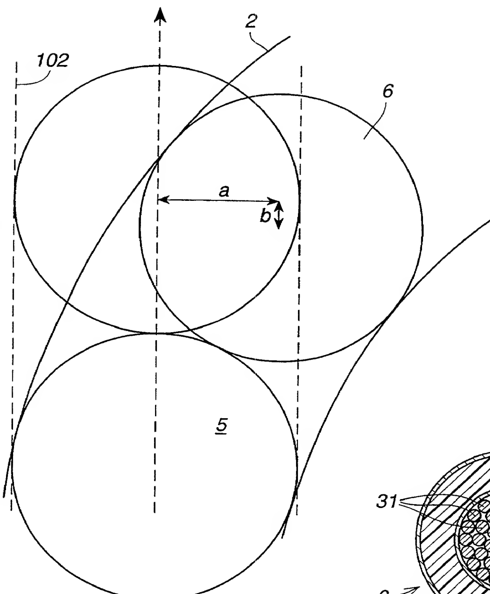

Fig. 7

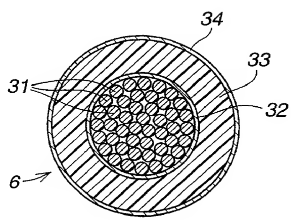

Fig. 8

Declaration, Power Of Attorney and Petition

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

A ROTATING ELECTRIC MACHINE WITH A MAGNETIC CORE

the specification of which

☐ is attached hereto.

☒X was filed on May 22, 2000 as

Application Serial No. ____________

and amended on ____________.

☒X was filed as PCT international application

Number PCT/SE98/02163

on November 27, 1998,

and was amended under PCT Article 19

on ____________ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed	
9704381-4	SWEDEN	27 November 1997	☒ Yes	☐ No
			☐ Yes	☐ No
			☐ Yes	☐ No
			☐ Yes	☐ No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application Number) (Filing Date)

(Application Number) (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)
PCT/SE98/02163	27 November 1998	

And we (I) hereby appoint: Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; William E. Beaumont, Reg. No. 30,996; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Christina M. Gadiano, Reg. No. 37,628; Jeffrey B. McIntyre, Reg. No. 36,867; William T. Enos, Reg. No. 33,128; Michael E. McCabe, Jr., Reg. No. 37,182; Bradley D. Lytle, Reg. No. 40,073; and Michael R. Casey, Reg. No. 40,294; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1-00 Jan HEMMINGSSON

NAME OF ~~FIRST~~ SOLE INVENTOR

Jan Hemmingsson

Signature of Inventor

Aug 3, 2000

Date

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